Consistent Particle-Continuum Modeling and Simulation of Flows in Strong Thermochemical Nonequilibrium

Completed Technology Project (2011 - 2015)

Project Introduction

During hypersonic entry into a planetary atmosphere, a spacecraft transitions from free-molecular flow conditions to fully continuum conditions. When modeling and predicting the aerothermal environment encompassing the vehicle, the direct simulation Monte Carlo (DSMC) particle method is used for the rarefied regime, whereas computational fluid dynamics (CFD) methods are used in the continuum regime. However, even within a mainly continuum flow, there may be local regions of nonequilibrium (rarefied flow) where the DSMC method is required for accuracy. Such regions include sharp leading edges, backshells of capsules, shock interactions, and possibly boundary layers. Similarly, in space, rocket plume flows transition from continuum inside the nozzle to rarefied in the plume. When rocket plumes resulting from on-orbit maneuvers impinge on other spacecraft surfaces, or when landing on a planetary (or asteroid) surface that has little atmosphere, the plume can become continuum again. For accurate simulation of such flows, a hybrid CFD-DSMC technique is required. This situation also arises in retro-rocket deceleration and aero-assist maneuvers high in a planetary atmosphere. Substantial progress has been made on such a coupled algorithm over the past decade, to the point where 2D/axi-symmetric flows with thermal nonequilibrium can be solved accurately. However, the applications for which a hybrid method is practically useful are flows where pure DSMC simulation is intractable. This inherently involves complex 3D flows at high speeds where chemical reactions occur. Currently, chemical models used in DSMC and CFD do not seem to agree in the continuum (overlap) regime as required for a robust hybrid method. This project will investigate consistent particle-continuum chemistry models and then implement these models within a hybrid method. This will involve developing methods for averaging over trace species in DSMC in order to provide low-scatter averaged values for CFD regions of the flow. The project will also seek to maintain particle and continuum simulation meshes completely decoupled which will be required for tackling 3D complex geometry flows. This will involve investigation of mesh interpolation strategies that conserve mass, momentum, and energy. The result of this project will be a fully capable hybrid CFD-DSMC code that can be applied to a wide range of actual NASA engineering applications. This new technology will constitute an accurate but general tool for solving a wide range of hypersonic flow problems spanning free-molecular to continuum.

Anticipated Benefits

The result of this project will be a fully capable hybrid CFD-DSMC code that can be applied to a wide range of actual NASA engineering applications. This new technology will constitute an accurate but general tool for solving a wide range of hypersonic flow problems spanning free-molecular to continuum.

Project Image Consistent Particle-Continuum Modeling and Simulation of Flows in Strong Thermochemical Nonequilibrium

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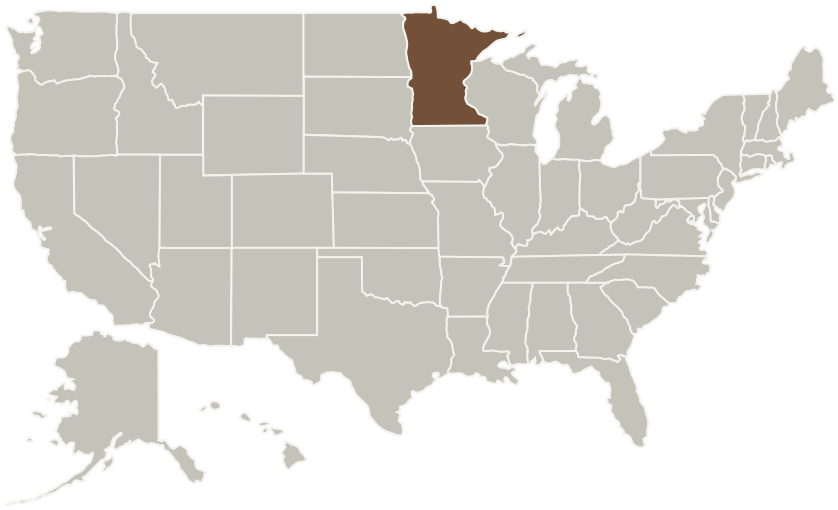
Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
University of Minnesota-Twin Cities	Supporting Organization	Academia	Minneapolis, Minnesota

Primary U.S. Work Locations
Minnesota

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

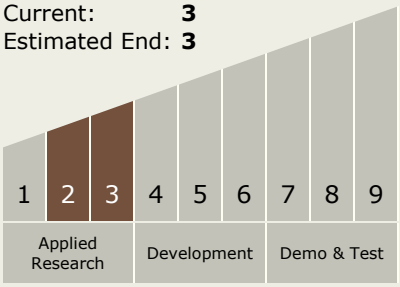
Thomas Schwartzentruber

Co-Investigator:

Byron T Edgar

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**



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Images

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Project Image Consistent Particle-Continuum Modeling and Simulation of Flows in Strong Thermochemical Nonequilibrium
(https://techport.nasa.gov/image/1734)

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Technology Areas

Primary:

- TX09 Entry, Descent, and Landing
  - TX09.4 Vehicle Systems
    - TX09.4.5 Modeling and Simulation for EDL